IDA

INSTITUTE FOR DEFENSE ANALYSES

Potential for Broader DoD Use of Commercial Turbine Engine Acquisition Practices and Processes

J. Richard Nelson, Project Leader
Bernard L. Retterer

November 1997

Approved for public release; distribution unlimited.

IDA Document D-1990

Log: H 97-000778

This work was conducted under contracts DASW01 94 C 0054/ DASW01 97 C 0056, Task T-F7-1010, for the Office of the Under Secretary of Defense (Acquisition and Technology)/Air Warfare. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

INSTITUTE FOR DEFENSE ANALYSES

IDA Document D-1990

Potential for Broader DoD Use of Commercial Turbine Engine Acquisition Practices and Processes

J. Richard Nelson, Project Leader
Bernard L. Retterer

PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) for the Office of the Director, Air Warfare, under a task entitled "Tactical Air Warfare Programs Technical and Schedule Risk Assessments." The overall task is directed toward the study of DoD weapon system acquisition technical and schedule risk assessment. This report addresses those issues as they relate to aircraft turbine engines (turbojet and turbofan) acquired and operated by the DoD.

This work was reviewed within IDA by Eugene E. Covert and Karen W. Tyson.

CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

The aircraft turbine engine is one of the more significant inventions of the 20th century. From its start prior to World War II, the aircraft turbine engine has significantly contributed to providing the means for the United States to protect itself and to project power to all corners of the earth. Commercial application of the turbine engine has fostered commerce and world travel on an unprecedented scale. The United States has maintained a leadership role in turbine engine technology, development, and production through the combined efforts of the commercial sector and the various government agencies (i.e., DoD, NASA, and FAA).

Complex state-of-the-art turbine engines are expensive to develop (exceeding $1 billion) and costly to produce ($1 million to $10 million each). The Department of Defense, seeking ways to reduce military expenditures, has recently turned its attention to lowering military aircraft costs through use of commercial processes and practices where such activities are deemed practical. Since turbine engines comprise a significant component of aircraft cost (15% to 25%), the factors that underlie engine acquisition and operating and support costs are being reviewed in this light. Turbine engines for the commercial airline market with characteristics comparable to similar military engines appear to cost less and take less time to develop and produce. In fact, commercial turbine engines are being used on several military subsonic tanker/transport aircraft (KC-135R and C-17). Such use is not unexpected since engine manufacturers develop and produce both military and commercial aircraft turbine engines using many common design and development processes and materials.

IDA was tasked to determine if commercial turbine engines could be used more broadly for military applications and if commercial turbine engine acquisition practices and processes could be used for military engine development and production. IDA conducted the study by acquiring and reviewing information from military and commercial sources related to military and commercial turbine engine development, production, and application. This study focused on turbojet and turbofan engine configurations and their associated acquisition issues. It is reasonable to expect that some of the findings could find practical application for turboshaft and turboprop engine

acquisitions. The conclusions and recommendations developed by the study are outlined below.

A. COST SAVINGS POTENTIAL

The primary reason for considering the use of commercial engines and acquisition processes by the military is the cost savings potential. Cost savings opportunities might include:

- Cost avoidance through elimination of certain engine development and production practices by reducing military specification management oversight requirements.
- Some engine development cost avoidance by using existing commercial products developed at the manufacturer's expense.[1]
- Production cost economies resulting from learning curve savings achieved by combining military requirements with the commercial production base.
- Engine production cost savings resulting from maintaining competition among the several engine manufacturers.
- Using the manufacturer's normal replacement parts inventory and facilities to reduce spares inventory costs.
- Cost avoidance from incorporation of the manufacturer's financed engine product improvement programs, avoiding some government-funded Component Improvement Programs (CIPs).
- Use of existing commercial engine maintenance resources to reduce maintenance facilities and support costs.

B. MILITARY USE OF COMMERCIAL ENGINES

Successful use of commercial turbine engines in military transport and similar utility aircraft has clearly shown that commercial practices and processes can be used to develop and produce engines usable by the military for these subsonic applications.

---

[1] Manufacturers obviously attempt to recover the cost of development by amortizing that expenditure across the expected engine sales base. By use of commercially developed products, the military avoids paying the full development cost up front.

However, the examination of the technical requirements for subsonic and supersonic aircraft engines found a number of design differences including:

- Experience accumulates rapidly for aircraft designed and developed for commercial applications, thereby providing more experience upon which to base product improvements.
- Fighter/attack aircraft missions require frequent throttle changes leading to numerous damaging pressure and temperature cycles during missions.
- Military aircraft operate to higher service ceilings (up to 80,000 feet) compared to commercial aircraft ceilings (50,000 feet).
- Supersonic aircraft turbine engines are generally mounted internally to achieve lower drag, creating more complex installation interfaces with the aircraft.
- Aircraft turbine engines operating in fighter/attack aircraft require higher performance designs and are more often subject to rotating stall and surge phenomenon than are subsonic commercial aircraft.
- Fighter/attack aircraft require light-weight, high-thrust engines to achieve superior performance and agility.
- Afterburner function is added to supersonic fighter/attack aircraft to increase thrust by up to 60% during critical mission phases, a capability not required by subsonic commercial aircraft.
- Engines for special military mission aircraft must be capable of accommodating high-energy fuels required by their unique flight profiles.
- Military stealth aircraft require control of radar reflections and infrared emissions from the aircraft engines.
- Engine-vectored-thrust technology permits air-superiority aircraft to gain a maneuverability advantage over adversary aircraft; this feature is not required by commercial or military transport aircraft, although commercial engines may employ thrust reversers.
- Rapid engine acceleration response is required for aircraft that operate from Navy carriers and for aircraft used in air-superiority roles.

Military procurements must address each of these requirements to ensure by design analysis and test that the engines acquired have the capability to meet mission requirements.

IDA recommends that commercial aircraft turbine engines be used where possible to take advantage of these cost saving opportunities. However, because commercial engines lack some of the characteristics needed for certain military aircraft applications

(fighter/attack aircraft), some military engines will need to be designed expressly to meet those operational needs.

C. ENGINE ACQUISITION PRACTICES AND PROCEDURES COMPARISON

The practices and procedures used to develop and produce military and commercial engines were reviewed and compared. The following similarities and differences were observed:

- Similarities
  - Share the same industrial base
  - Common production facilities
  - Similar development, manufacture, and support processes
  - Share many technology developments
  - Several engine types are used by both military and commercial customers
  - Verification tests cover many of the same parameters
  - Designs stress low ozone, smoke, and noise emissions
  - Share parts and materials vendors
  - Configuration control is required
  - Share some design procedures and engineering standards
- Differences
  - Fighter/attack engines are multi-point designs; commercial engines are single-point designs
  - Military funds engine development and retains data rights
  - Military directs and controls engine development and production and requires the delivery of extensive data for review and approval
  - Military audits the engine manufacturer's cost and negotiates profit margins
  - Military normally competes design program definition and awards engine development and production sole source, although production competition has occurred (F-16C/D)
  - Military has funded extensive CIP efforts to improve engine durability as shown to be needed by operational experience

- Military procurement regulations have posed obstacles to the purchase of commercial engines in the open market, but, through persistence, these obstacles have been surmounted
- Commercial engine manufacturers establish characteristics for engines they intend to develop in cooperation with commercial airplane manufacturers and customers
- Engine manufacturers fund development of commercial engines and retain data rights
- Commercial engines take 4-6 years to develop while military engines take 5-10 years, nominally
- Engine manufacturers direct and control commercial engine development, production and what would be characterized as CIP
- Commercial manufacturers set price (and profits) by negotiation in an open competitive market
- Commercial aircraft customers compete engine applications
- Commercial aircraft customers often rely on engine manufacturers or third parties for operational and maintenance support
- Requirements for military engines for supersonic fighter/attack applications are more demanding than for commercial engines and tend to push the state of the art, creating higher risk programs
- Fighter/attack aircraft engines have requirements for low radio frequency/infrared observables

D. CONCLUSIONS

Conclusions drawn from this study include:

- The commercial aircraft turbine engine acquisition process has been proven to produce high-quality, efficiently operating engines for subsonic cruise flight applications capable of achieving desired operating characteristics at costs less than their military equivalents.
- Commercial engine processes in the United States are not now intended to provide engines to meet supersonic flight requirements.
- Engines developed for commercial use have the thrust and operating characteristics that meet many of the military subsonic aircraft engine requirements related to transport, unmanned air vehicles, utility aircraft, and selected bomber applications. This has been proven by the actual use of commercial engines for military applications such as the C-17 and the KC-135R.

- The decision to re-engine a military subsonic aircraft requires that the aircraft performance be shown to improve significantly and that the projected operating and support cost savings exceed the cost of acquiring, integrating, testing and installing new engines (e.g., KC-135R).
- The feasibility of using commercial engine acquisition practices for the acquisition of high-performance, supersonic military aircraft engines has not been tried and is not considered likely.

E. RECOMMENDATIONS

- The DoD should continue to make use of current commercial subsonic engine products for both engine retrofit (KC-135R) and new production (C-17).
- The DoD should use the commercial engine development process and FAA oversight procedures to the extent practicable for subsonic transports, tankers, unmanned air vehicles, utility aircraft, and selected bomber applications.
- Fighter/attack aircraft engine development should make use of selected commercial practices, including use of integrated product teams, design to unit cost, and simulation and modeling.
- Military engine support may be streamlined by using commercial practices related to data, technical documents, and support equipment.
- Spares inventory for commercial engines in military applications may be reduced by making use of engine manufacturers' spares facilities and resources. Provision must be made to accommodate wartime requirement surges.
- The DoD should review procurement processes to reduce complexity and remove obstacles to the military use of commercial products.
- The DoD should continue to sponsor turbine engine technology development for subsonic and supersonic flight to maintain the US leadership role.
- The DoD should continue to sponsor CIP for military engines to ensure safety of flight and operability, supportability, and durability.

I. INTRODUCTION

A. STUDY OBJECTIVES

The aircraft turbine engine is one of the more significant inventions of the 20th century. From its start in World War II, the turbine engine has significantly contributed to providing the means for the United States to protect itself and to project power to all corners of the earth. Commercial application of the turbine engine has fostered commerce and world travel on an unprecedented scale. The United States has maintained a leadership role in turbine engine technology, development, and production through the combined efforts of the commercial sector and the various government agencies (i.e., military, NASA, and FAA). Complex state-of-the-art turbine engines are expensive to develop (exceeding $1 billion) and costly to produce ($1 million to $10 million each).

This task investigates the potential use by the military of commercial turbine engine (turbojet/turbofan) acquisition practices and processes. This commercial acquisition process includes the Federal Aviation Administration (FAA) certification procedure for aircraft turbine engines. The objective was to identify ways to reduce military expenditures in the face of shrinking defense budgets through use of commercial practices and processes. The focus on aircraft engines is due to their being a critical military subsystem with a long development period, high production cost ($1 million to $10 million for subsonic applications), and higher support costs in military applications. The commercial sector has developed and produced cost-effective subsonic engines. This study assessed the extent to which commercial engines can be used for military aircraft and the degree that elements of commercial acquisition practices and processes are applicable to military turbine engine development and procurement in general.

This study performed the following subtasks:

- Reviewed the extent to which commercial engines can meet military aircraft application requirements.
- Compared commercial aircraft turbine engine acquisition practices and processes to those used by the military.
- Evaluated the feasibility of broader DoD use of commercial industry aircraft turbine engine acquisition practices and processes.

The subtasks were accomplished by acquiring and reviewing data and information that discuss the merits of commercial and military turbine engine acquisition practices and processes.

B. BACKGROUND

In April 1993, the Under Secretary of Defense (Acquisition and Technology) asked the Defense Science Board (DSB) to define possible improvements in the process the DoD uses to acquire goods and services. As an extension of this initiative, the Chairman of the DSB Defense Acquisition Reform Task Force in September 1993 formed a study panel to examine the feasibility of procuring all military jet engines using commercial practices.

The panel reached the following conclusions:

> 1) It is feasible and desirable to use commercial practices, industry wide, to procure and support mature military engine production;[1] and 2) It is not appropriate, at this time, to use purely commercial practices in the research and development phase of the acquisition cycle for large military engines. There are opportunities, however in the development of smaller engines for target or reconnaissance vehicles.[2]

The panel's principal recommendations were:

> 1) A detailed comprehensive program be established to convert the military jet engine industry to commercial practices for procuring, and supporting mature engine production and support programs; and, 2) The Administration, Congress and Department of Defense provide the necessary waivers and exceptions to the various laws, regulations, standards and specifications that will allow pure commercial practices to be used to procure and support mature military engine production and support programs....

The panel also noted "that the program must be implemented in its entirety, across the jet engine industry, for all in-production engines. Partial implementation of a few

---

1 Although not defined by the DSB, an engine is considered mature if it 1) has completed and passed all development, qualification, and operational tests, 2) has successfully entered full-rate production, 3) has been installed and is operating in targeted aircraft, and 4) is meeting all performance and operating and support goals.

2 Office of the Under Secretary of Defense for Acquisition and Technology, *The Report of Defense Science Board Task Force, Jet Engine Commercial Practices Panel Final Report, Appendix D*, May 1994.

engine models, facilities or companies will not generate the government or industry commitment needed for success."

As part of its technology and schedule risk assessment task for the Office of the Under Secretary of Defense (Acquisition and Technology), IDA was requested to undertake this examination of technology and procurement issues associated with the military use of commercial aircraft turbine engine acquisition practices and processes. While commercial practices have been shown to be effective for subsonic applications there is concern that they may not be sufficient to develop or produce engines for supersonic aircraft. These technology issues were assessed during this investigation.

C. REPORT OVERVIEW

Chapter I has described the study and outlined the study objectives. Engine design and related technology issues that may differ for subsonic and supersonic aircraft applications are explored in Chapter II. Chapter III compares military and commercial engine acquisition practices and processes. Issues to be considered include the engine market and interfaces; industrial base; technology and design transition and verification; life-cycle planning; technical, financial and management risk and controls; engine development and improvement processes; system integration; and test verification. Chapter IV presents the conclusions and recommendations emanating from this study. An appendix provides information on major US military subsonic and supersonic aircraft and their associated engines.

II. MILITARY AND COMMERCIAL AIRCRAFT TURBINE ENGINE DESIGN COMPARISONS

A. INTRODUCTION

The primary issue in this task is the applicability of commercial practices and procedures to the acquisition of military aircraft turbojet/turbofan engines across the spectrum from subsonic to high-performance supersonic aircraft. The commercial techniques' applicability for both development and production have been demonstrated for subsonic transport and utility aircraft with the successful use of commercial engines in aircraft such as the C-17, KC-10, and KC-135R. However, the case for using these commercial procedures for either development or production of engines for supersonic high-performance aircraft has not been demonstrated in the United States. Further there is concern that some of the practices may not be appropriate or may require modification. This chapter reviews and identifies some of the major engine design issues that differ for military supersonic fighter/attack aircraft compared to subsonic bomber, transport, unmanned air vehicles, and utility aircraft applications. Where design requirements are found to differ, the acquisition practices or procedures that might be affected are identified.

B. COST SAVING POTENTIAL

The primary reason for considering the use of commercial engines and their acquisition processes by the military is their cost saving potential. Cost saving opportunities might include:

- Cost avoidance through elimination of certain engine development and production practices by reducing military specification management oversight requirements.
- Some engine development cost avoidance by using existing commercial products developed at the manufacturer's expense.
- Production cost economies resulting from learning curve savings achieved by combining military requirements with the commercial production base.

- Engine production cost savings resulting from maintaining competition among the several engine manufacturers.
- Using the manufacturer's normal replacement parts inventory and facilities to reduce spares inventory costs.
- Cost avoidance from incorporation of the manufacturer's financed engine product improvement programs avoiding some government-funded CIPs.
- Use of existing commercial engine maintenance resources to reduce maintenance facilities and support costs.

Use of engines developed for the commercial market where possible to take advantage of these cost saving opportunities is obviously recommended. However, there are many military aircraft applications (most fighter/attack aircraft) that require engine characteristics that are not provided by commercial engines.

Where it is not possible to use commercial engines, an alternative would be for the DoD to use commercial acquisition practices and processes for the development and production of engines that are designed to meet military requirements. The Carnegie Commission on Science Technology and Government[1] calculated that the management and control costs associated with the DoD acquisition process were about 40 percent of the acquisition budget compared to 5-15 percent for commercial firms. In the balance of this chapter, we review the characteristics of military engine requirements that could preclude the use of existing commercial products and/or acquisition practices or processes.

C. MILITARY ENGINE UNIQUE REQUIREMENTS

Military transport and utility aircraft have operating profiles similar to commercial airplanes and consequently are prime candidates for use of commercial engines. However, fighter/attack aircraft have totally different mission profiles dictating capability that commercial engines do not currently provide. The appendix to this report summarizes the engines used by on the major United States military subsonic and supersonic aircraft. Table II-1 provides a comparison between military and commercial engine design requirements. The discussion that follows reviews these requirements in more detail.

---

1 Carnegie Commission on Science Technology and Government, *A Radical Reform of the Defense Acquisition System*, December 1992.

Table II-1. Engine Design Requirements Comparison

Requirement	Military	Commercial
Thrust Capabilities	Requirements to 50,000 lb.	Requirements to 100,000 pounds
Experience Accumulation Rates	1,000 to 1,500 hours per year for transports, 300 hours per year for fighter/attack aircraft	3,000 hours per year for subsonic transports
Throttle Control Mission Use	Flight profiles require frequent engine stressing throttle changes	Limited throttle changes during take-offs and landings
Service Ceiling	Up to 80,000 feet	Up to 50,000 feet
Engine Installation	Supersonic aircraft engines typically are installed internally creating complex interface	Engines are typically mounted on wing pylons creating less complex interface
Rotating Stall and Surge	Common problem for supersonic aircraft engine	Infrequent problem for subsonic applications
Thrust-to-Weight Ratio	10:1 for high performance fighter/attack applications	To 6:1 for transports. Emphasis on high fuel efficiency and reliability
Afterburner	Required for fighter/attack for mission performance enhancement	Not used (US aircraft)
High Energy Fuels	Used for selected aircraft with unique high performance requirements	Not used
Stealth Characteristics	Required for some fighter/attack aircraft	Not required
Vectored Thrust	Used for air-superiority aircraft flight control	Thrust reversers used for landings
Rapid Acceleration	Very fast engine response and acceleration required for carrier landings and air-superiority applications	Fast engine response and acceleration

1. Thrust Capabilities

Turbine engine thrust ranges from 5,000 to about 50,000 pounds for military subsonic and supersonic aircraft now in the inventory. Commercial aircraft which put an emphasis on high fuel efficiency and low maintenance costs use engines that have thrust capability projected to 100,000 pounds (GE90). Clearly, the commercial processes can produce large reliable and fuel efficient engines. Fuel efficiency is achieved by the use of turbofan designs producing high bypass ratios (ratio of air volume through the fan bypass ducts versus air volume through the hot section). These commercial engines are appropriate for subsonic military transport, tanker, unmanned air vehicles, utility aircraft, and some bomber applications.

Military supersonic fighter/attack aircraft engines have other requirements that must be considered in addition to thrust and fuel efficiency. These requirements include ability to operate at high altitude and high speed. High speed operation dictates the use of low bypass ratios. Other fighter/attack aircraft engine requirements that must be considered include high thrust-to-weight ratios, thrust augmentation, stealth capability, ability to use special fuels, and vectored thrust.

2. Experience Accumulation Rates

Commercial and military transports accumulate operating hours at the rate of 3,000 hours per year for the former and approximately 1,000 hours for the latter. Operating experience accumulates rapidly across a fleet of aircraft at these rates providing the basis for early engine problem identification and improvement. Typical fighter/attack aircraft accumulate operating experience much more slowly, at the rate of about 300 hours per year. As a consequence, it is more difficult to identify early and resolve latent fighter/attack aircraft engine design problems.

3. Throttle Control Mission Use

The operating profiles differ significantly between transport and fighter/attack aircraft. Transport engines run at near-maximum power at takeoff and are reduced to the cruise power position after reaching altitude. Slight changes in power settings may occur during the flight to adjust for minor speed and altitude changes. Another high power cycle may occur during the aircraft landing for reversed thrust.

Fighter/attack aircraft follow a profile similar to transports for the cruise to the mission area in that they fly formations that require frequent small throttle changes to maintain their relative positions. During a hostile engagement the throttle settings may be changed many times from full to idle producing numerous engine temperature and pressure cycles. These cycles to the extreme limits accelerate engine wear and can lead to material breakdown and engine failure.

4. Service Ceiling

Commercial subsonic aircraft service ceilings range up to 50,000 feet (Boeing 777 ceiling is 44,000 feet) whereas military aircraft ceilings can run as high as 80,000 feet or more. Most military fighter/attack planes have service ceilings that extend up to 65,000 feet. Operation at these higher altitudes requires that the engine and the air inlets be specifically designed to provide the airflow necessary over a wide range of air densities.

Commercial test procedures do not currently evaluate aircraft engine performance above the 50,000 feet flight level.

5. Engine Installation

Currently, with one exception (the Concorde) commercial airlines use only subsonic aircraft. Subsonic aircraft engines are typically fitted into nacelles which are installed on pylons attached to the wings or the rear fuselage for some twin- or three-engine applications. The wing pylon configuration creates a well defined simpler interface between engine and aircraft. Integration of an engine into a subsonic airframe is a much simpler task than for a supersonic aircraft. Commercial acquisition practices are more geared toward implementing the union of this comparatively simple engine-aircraft interface.

The pylon engine mounting concept is normally not used for military supersonic aircraft (the B-1 might be considered an exception) with most supersonic aircraft engines mounted internally. Internal engine mounting produces a clean aerodynamic design. However, the engine inlet and exhaust interfaces for supersonic aircraft are very complex requiring detailed design analysis, and supersonic wind tunnel evaluation followed by a rigorous flight test program.

6. Rotating Stall and Surge[2]

A basic principle in the design of jet engines is to keep the air flowing smoothly in the front and out the back, a pattern more difficult to achieve than it would at first seem. At supersonic speeds matching engine air flow requirements requires special mechanical treatment of the inlets and exhaust ducts. Under adverse conditions the smooth air flow can be disrupted. The air flow within the engine occasionally begins to pulse and can be sufficiently severe that the flow can be disrupted and even momentarily reverse direction, a condition known as surge. The resulting power loss can obviously be critical to aircraft and damaging to the engine. Another related damaging flow problem is called rotating or stagnation stall.

In the late 1980s researchers at MIT Gas Turbine Laboratory determined that rotating stall can be predicted based on information derived from an array of engine pressure measurement sensors. Once the pre-stall wave pattern is detected, actuators can

---

2 "Air and Space Futures," April/May 1996, *Air & Space/Smithsonian Magazine*.

be energized to dampen the initial surge thus preventing stall and the attendant power loss. Pratt & Whitney is incorporating this technology into the F119 engine, and it will be first tried on the F-22 aircraft.

Although vital to supersonic flighter/attack applications, the anti-stall and surge technology is not as critical for subsonic operation where the problem occurs less frequently. However, due to the protection afforded, it is expected that the anti-stall and surge technology will find application for both military subsonic and commercial aircraft.

7. Thrust-to-Weight Ratio

Combat effectiveness of a fighter/attack aircraft requires that it have superior speed and maneuver capability over its potential adversaries. This translates to a need for an aircraft that has high thrust for superior climb and speed capability. Engines must be light in weight with a low inertial mass enhancing aircraft acceleration and maneuvering characteristics. Thus the thrust-to-weight ratio is an important engine performance measure. Commercial aircraft typically use engines that have thrust-to weight-ratios of 5:1 to 6: 1, whereas engines used in supersonic applications typically have ratios ranging from 7:1 to 10:1.

Engine combustor temperature, compression ratio, mass flow and centrifugal stresses are the key factors in gas turbine design that limit both unit size and efficiency. For example a 55C temperature increase in turbine inlet temperature gives a 10-13 percent output increase and a 2-4 percent efficiency improvement.[3] The most critical area of a gas turbine for determining the efficiency and life is the hot path i.e., the combustion chamber and turbine stages, containing stationary nozzles and rotating blades.

The high thrust-to-weight ratios needed for supersonic aircraft engines require that technology/materials be found that permit the increase of operating temperatures and pressures, and have the capability of withstanding the severe operating environment. An example of new technology that was introduced in military engine design to provide higher operating temperatures is single crystal metals that increase the strength of turbine blades. Air cooling technology has been developed for turbine blades that permits the turbine to run at higher internal temperature while protecting the blades from damage. The higher temperature produces greater thrust and improved efficiency but sometimes at the expense of reduced reliability and higher maintenance cost. Subsonic commercial

---

3 *Gas Turbine Design*, http://www.worldbank.o.../thrmtech/gascsubs.htm

engines for transport and utility applications are more conservatively designed, thus focus on achieving fuel efficiency, high reliability and low maintenance cost. Military fighter/attack engines tend to focus on performance and rightly so, but at the expense of durability and reliability.

8. Afterburner

Afterburners have been added to current supersonic aircraft engines providing a means to increase thrust by about 60 percent for short periods of time. Additional fuel is injected into the engine exhaust chamber where it is burned adding significant energy to the exhaust airmass volume. Because afterburners burn fuel at a high rate they are used only when needed for short mission performance enhancement bursts. The advent of supercruise engines will permit sustained aircraft operation at supersonic speeds while the engine is in military power (non-afterburner mode).

9. High-Energy Fuels

Another technique for achieving high thrust to meet unique operational requirements is the use of special high energy fuels. Engines must be modified to accommodate these fuels. High heat sink fuels[4] such as JP8 +100 are also being developed to provide a means of cooling avionics, improve engine operating characteristics and reduce aircraft fuel system maintenance requirements. The commercial processes would require modification to test and evaluate these fuel alternatives.

10. Stealth Characteristics

Large engine inlet and exhaust diameters along with the structural configuration can form radio frequency reflectors capable of creating unacceptable radar cross-sections. Also the large volume high temperature gas emissions from engines can generate large infrared signatures. The large radar and infrared signatures produced by commercial engines would in most cases exceed military stealth limits. Radar and infrared signatures are typically not of interest for commercial engines and therefore are not currently controlled in the commercial acquisition processes.

---

4 High Speed Propulsion & Fuels, http://www.dtic.mil/cgi-b

11. Vectored Thrust

Recent military engine designs have been developed that provide a method to direct the exhaust flow off the aircraft centerline. This creates a thrust vector that can rapidly change the attitude of an aircraft in response to steering commands implemented via a fly-by-wire system. This capability provides air-superiority fighter aircraft with the ability to maneuver rapidly, an advantage over potential adversary aircraft. This capability is not required by most military or commercial aircraft. Vectored thrust could ultimately lead to tailess aircraft providing significantly improved cruise lift-to-drag ratios, which would be quite advantageous for commercial aircraft.

12. Rapid Acceleration

Several military applications require engines that respond quickly to throttle commands, accelerating rapidly to provide full thrust. Aircraft that operate from Navy aircraft carriers require this capability to recover from missed landings. Air-superiority aircraft also benefit from rapid acceleration as a means to out-maneuver an opponent in a "dog-fight." Commercial application operating profiles typically do not require rapid engine response. Although commercial aircraft have missed landings, the margin of error is generally greater than the response required for Navy carrier operation.

D. SUMMARY

Successful use of commercial turbine engines in military transport and similar utility aircraft has clearly shown that the commercial practices and processes can be used to develop and produce engines usable by the military for these subsonic applications. However, our examination of the technical requirements for subsonic and supersonic aircraft engines found there to be a number of design differences including:

- Experience accumulates rapidly for aircraft designed and developed for commercial applications thereby providing more rapidly operating experience upon which to base product improvements.
- Fighter/attack aircraft missions require frequent throttle changes leading to numerous damaging pressure and temperature cycles during missions.
- Military aircraft operate to higher service ceilings (up to 80,000 feet) compared to commercial aircraft levels (50,000 feet).
- Supersonic aircraft engines are generally mounted internally to achieve lower drag, creating more complex installation interfaces with the aircraft.

- Aircraft turbine engines operating in fighter/attack aircraft require higher performance designs and are more often subject to rotating stall and surge phenomenon than are subsonic commercial aircraft.
- Fighter/attack aircraft require light-weight high-thrust engines to achieve superior performance and agility.
- Afterburner function is added to supersonic fighter/attack aircraft to increase thrust by up to 60% during critical mission phases, a capability not required by commercial aircraft.
- Engines for special mission aircraft must be capable of accommodating high energy fuels required by the unique flight profiles.
- Military stealth requirements require control of radar reflections and infrared emissions from the aircraft engines.
- Engine-vectored-thrust technology permits air-superiority aircraft to gain maneuverability advantage over adversary aircraft; this feature is not required by commercial or military transport aircraft, although commercial engines may employ thrust reversers.
- Rapid engine acceleration response is required for aircraft that operate from Navy carriers and for aircraft used in air-superiority roles.

Military procurements must address each of these requirements to assure by design analysis and test that the engines acquired have the capability to meet mission requirements. Commercial engine developments typically do not address any of these unique military requirements. Rather, they focus on delivering an engine that will function in the comparatively benign commercial airline environment delivering the required thrust and achieving the specified fuel economy goals. Adoption directly of the commercial system for all military engines cannot be recommended because it has not demonstrated that it could develop engines meeting the added military requirements. However, past the development phase, the commercial production oversight procedures may be applicable to mature engine production. Alternatively, it is expected there may be elements that could be used directly or modified to speed and or reduce the cost of engine acquisition. The next chapter of this report reviews and compares elements of the military and commercial acquisition processes and addresses the suitability of commercial practice for military acquisition.

III. ACQUISITION PROCESS COMPARISON

A. INTRODUCTION

It is necessary to compare the commercial and the military approaches to engine acquisition and ownership side-by-side to gain insight regarding which of the commercial acquisition practices or processes might be appropriate and of value for adoption by the military. The comparison encompassed the range of acquisition activities required to plan, fund, develop, produce and operationally support a typical aircraft turbine engine acquisition.[1] Because of the common roots for commercial and military engines, the acquisition practices and processes were found to be similar differing only in the scope and extent to which they are applied. The applicability to the military of each of the commercial acquisition practices was reviewed and their possible utility was evaluated.

B. MARKET COMPARISON

1. Acquisition Process

The total engine market may be divided into three segments including (1) the world commercial segment, (2) the US military, and (3) the foreign military. The world commercial segment is the largest followed by the US military. The foreign military market to some degree tends to follow US military aircraft procurement programs. These markets are all served by 10 major engine manufacturers[2] that individually (in most cases) supply engines to all three markets. A variety of methods have been used for the acquisition of both military and commercial engines. The normal or typical processes used by both communities are outlined in Table III-1. The table presents a summary of the characteristics of the military and commercial markets in terms of (1) direction, control, and visibility, (2) source of funds, and (3) general business approach. Two alternative

---

1 Acquisition as used in this study is the sum of all activities associated with obtaining an engine including specification of requirements, design/development, test and evaluation, manufacturing, and initial support for operational use, but not recurring annual support.

2 General Electric, Pratt & Whitney, Rolls Royce, and CFM International have over 90% of the aircraft turbine engine market.

acquisition approaches that have been considered by the military are reviewed at the end of this chapter.

Table III-1. Military and Commercial Aircraft Turbine Engine Market Comparison

Issues	Military Programs	Commercial Programs
Direction, Control, and Visibility	Customer (Army, Navy, Air Force)	Contractor (engine company)
	Directs contractor work effort	Directs own effort
	Owns design and data rights	Owns design and data rights
	Controls configuration	Controls configuration
	Holds marketing rights	Develops market and strategy
	Sets profit level	Sets pricing level based on market
	Pays for development and improvement costs	Recoups development and improvement costs and program launching costs in sales revenue
Source of Funds		
Production Engines	Procurement contract	Customer orders
Spare Parts	Procurement contract	Customer orders
Product Improvement	CIP contracts	Sales revenues
Warranty	Procurement contract	Sales revenue
Engine Model Enhancements	EMDP[a] development contracts then CIP	Own funds depending on competition
Technology Advancements	IR&D, development contracts, discretionary	Sales revenue, IR&D, profit
Development	Development contract (government risk mostly)	Sales revenue, IR&D, profit
Overhaul	Customer or contractor fund	Airlines fund
Business Approach		
Establish Revenues	Cost established and "allowable" profit added through government audit process	Prices established by negotiation with customer
Allocation of Revenues	Segregated by engine model	Allocation at contractor's discretion
Business Base	Determined by government; competition may lower cost, increase efficiency and provide larger industrial base; may also lessen company sales base and shift discretionary funds	Includes all sales (no breakout)

[a] Engine Model Derivative Program

a. Military Market

The military engine development process begins with the government developing detailed engine technical requirements. Quite often these requirements may dictate design choices that are at or extend the state of the art and may require the development of new materials or processes to transition design to operational status. Fighter/attack aircraft to achieve performance superiority over potential advisories demand state-of-the-art capability. Funding for the development effort is most often provided by the military with the contractor being selected as the result of competitive bidding. Some engine manufacturers may invest their own IR&D funds to sponsor initial engine development work to enhance their competitive position. Overall military engine development can take from 5 to 10 years for a new engine design, and timing is sometimes dictated by the phasing of funding rather than by technical considerations alone. This is contrasted with the 4-6 years required to develop a commercial engine that achieves economies by maintaining program continuity by providing full development funding, requiring minimal documentation, reducing management oversight, and using optimized development and test programs.

The military contract directs that specified engine technical requirements be demonstrated and documented through design analysis disclosures and tests. Failure to meet the requirements leads to program delays and cost overruns. Most development contracts are issued on a cost basis which requires the government to pay for some specified portion of the cost overrun. Since the newly developed engine is unique, the government generally has no choice, but to issue a sole source contract to the development contractor for the initial production quantity. The DoD has for several large aircraft programs introduced competition for the engine production procurement by introducing a second engine source (see subsequent discussion of the F-15/F-16 program). The Government attempts to control cost through a rigorous cost disclosure and audit process imposed as part of the production contract and requires the contractor to defend his costs. Figure III-1 summarizes the current military turbine engine acquisition process.

Fighter/attack aircraft build operating time at the rate of about 300 hours per aircraft per year. This low service time accumulation rate requires several years to build an experience base suitable for latent defect identification and resolution. Use has been made of Accelerated Mission Testing (AMT), inflight engine monitors and Lead-the-Force testing initiatives to improve engine maturation rate. The military have made

limited use of short term (1-3 years) warranties for several engine programs providing failure information feedback to the engine manufacturer.

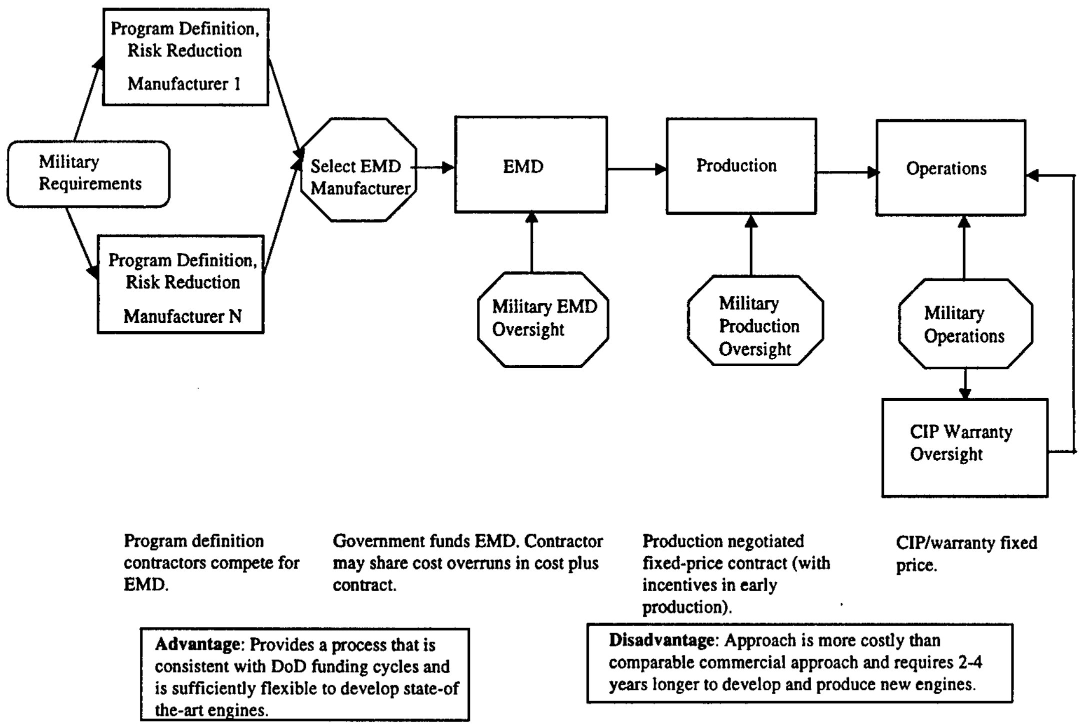

Figure III-1. Current Military Turbine Engine Acquisition Process

The DoD has funded component improvement programs (CIP) with the manufacturer to correct problems discovered during operation. The objectives of CIP programs include efforts to correct:

- Degradation of safety of flight (precludes class A accidents)
- Service deficiencies
- Reliability/durability problems
- LCC cost shortfalls

CIP programs have ranged in value from several millions to several hundred millions of dollars. There has been a trend to restrict CIP efforts to reduce engine deficiencies and not to fund engine capability growth.

b. Commercial Market

The commercial engine market for the most part is comprised of the world airlines (UAL, AA, Air France, etc.) and the air-freight companies (Federal Express et al.) as the

ultimate customers. The airframe manufacturers or their subcontractors often represent an intermediary agent that designs the engine installation and performs the required integration and test. The aircraft customers (airline and/or air freight operator) work closely with the airframe builder in selecting the specific engine that will be installed in the customers aircraft from among several competitive choices.

Engine manufacturers for the commercial market internally fund the development of engines that the company believes will have a sufficient market to recover their investment and to return a profit. The performance requirements for the commercial engines are determined by the engine developer drawing on inputs from airframe manufacturers and potential customers. Sale of the engine often will carry performance guarantees for fuel consumption and durability. Failure to meet the guaranties may require the engine manufacture to correct the deficiency and/or provide monetary compensation. The engine manufacturer conducts analysis and performs sufficient tests of his choosing to reasonably assure achievement of the guaranteed performance. The developed engine also is subjected to a range of tests required by the FAA to demonstrate air worthiness. Figure III-2 summarizes the current commercial turbine engine acquisition process.

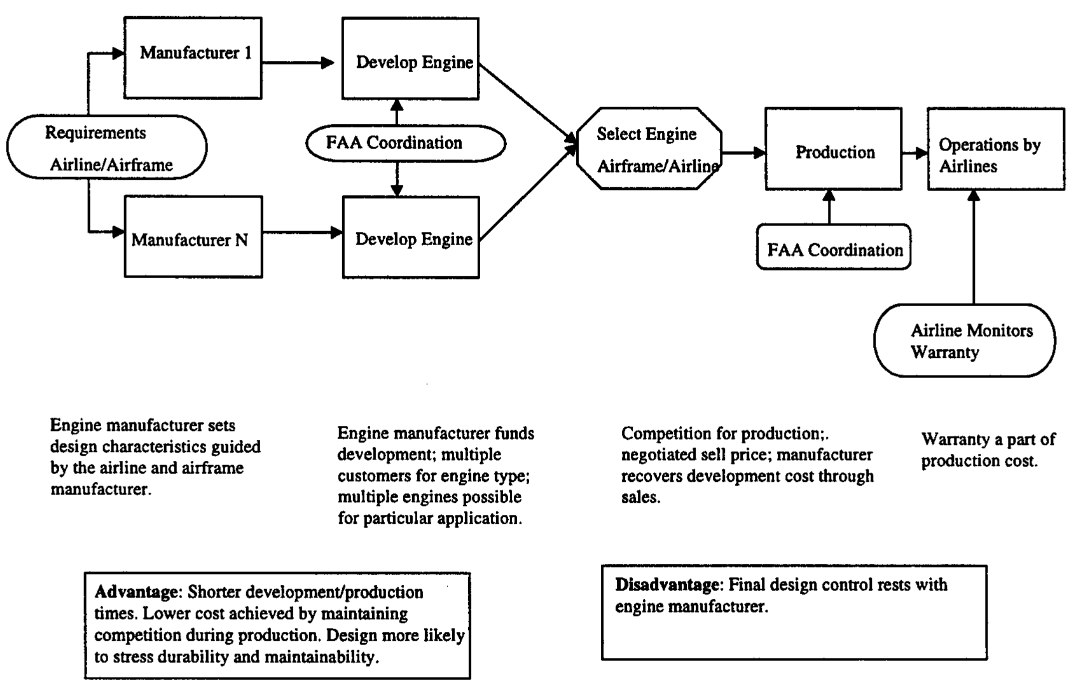

Figure III-2. Current Commercial Turbine Engine Acquisition Process

Because of market competition, there are often several engine choices available that will meet the propulsion requirements for a specific aircraft model. As a consequence, it is not unusual to find several different engine types installed in the same aircraft series. The choice is predicated on a range of factors including cost, the expected engine performance (thrust, fuel economy, etc.), and the airline customer's preference based on his prior experience with an engine manufacturer in terms of warranty, reliability, spares support, and operational performance. There are also cases where the airframe manufacture will select the engine and offer an airframe-engine package to potential customers.

After the engines are placed in service, the manufacturer provides engineering support to correct any shortfalls that may be revealed by operational experience. Airline usage rates (up to 3,000 hours per year) build a significant experience base rapidly leading to early problem identification and resolution aided by the feedback provided by the contract warranty arrangements. The engine manufacturer is contractually committed to correct or pay restitution for shortfalls covered by the procurement warranty/guarantees. For problems that occur outside this coverage, the manufacturer may be motivated to correct such problems to maintain the good will of his airline customers.

c. Summary

The military approach can be characterized as a somewhat rigid process where requirements are defined by the government (the customer) and achievement must be demonstrated. This approach has been found to be effective in advancing engine technology state-of-the-art and has been the source for much innovation in engine design. The military development process also has been effective in transitioning new technology to operational use by providing the management oversight and rigorous testing process as necessary to solve design and application problems. The principal disadvantages include potential for cost overruns during development if difficult technical problems are encountered due to the level of innovation required. Other disadvantages include expensive management oversight and documentation burden required for requirements compliance demonstration, and the lack of competition for engine production.

The commercial engine manufacturer guided by customer surveys determines the characteristics of the engines he plans for the airline market. The manufacturer may offer selected fuel consumption and durability guarantees or warranties to facilitate sales. The manufacturer will perform internal tests and analysis to assure that the product meets these goals. Formal testing and documentation is limited to that required to show

compliance with FAA air worthiness requirements. The principal advantage of the commercial approach is the cost saving resulting from a streamlined development process (funded by the manufacturer) and the presence of multiple sources for production. The principal disadvantage is the inability of the customer to directly control engine design.

2. Alternative DoD Acquisition Methods

The DoD has sought alternative approaches for engine acquisition in their attempts to reduce engine ownership costs. Two examples of these efforts are summarized below. The first approach addressed the problem of no competition for engine production by introducing a second source for a major engine buy. The second approach considered the use of leasing instead of outright purchase of the engines.

a. Production Competition

The military have introduced competition into turbine engine acquisition previously and is best illustrated by what has become known as the "Great Engine War." This refers to the intense competition that occurred between Pratt & Whitney (P&W) and General Electric (GE) to produce jet engines for the USAF F-15 and F-16 aircraft.

P&W was issued a contract in 1970 to develop the F100 engine for the F-15. The program experienced problems leading to schedule slippage. In an attempt to bring the engine development schedule back in line with the rest of the F-15 program, a modified Mission Qualification Test was authorized by the Air Force. As a consequence, the F100 entered production before it was completely tested and evaluated.

Major operational performance problems with the F100 engine, along a significant increase in the cost of parts for the P&W engine, and the large planned engine buy for the F-16 aircraft, led the Air Force to seek alternative solutions.

In the late 1970s, the Air Force issued GE a contract to develop a Derivative Fighter Engine for application to the F-16. In response to the contract, GE developed the F110 engine which was derived from the core of their B-1 F101 engine. The F110 engine was successfully flown in 1981. Based on this success, the Air Force decided to re-institute competitive engine procurement.

Currently both GE and P&W engines are used in the military inventory:

- P&W engines are used exclusively in the F-15 and two versions of the F-16 (A&B).

- GE engines are used in the two newer versions of the F-16 (C&D models) and the Navy F-14D.
- Based on the USAF decision to use the F110 engine, F-16 sales to Israel and Turkey have included GE engines.

Subsequent engine purchases have continued to be divided between the two companies to maintain an active competition.

Recently P&W was selected for the Joint Strike Fighter (JSF) Demonstration/ Validation with a derivative of the F119 engine. The F119 engine is being developed for the F-22 aircraft program, and its design is making use of technology developed from the F100 engine experience.

Since a total of 3,000 JSF aircraft are planned, the DoD has instituted another engine competition. A GE/Allison/Rolls Royce team will compete with Pratt & Whitney for a share of the JSF engine production. The JSF engine competition will be conducted using the same principals employed in the prior "Great Engine War." The two engines are expected to compete for JSF procurement in Lot V. The idea is to insure that the DoD will continue to have two viable sources for fighter engines. The engine competition will provide leverage to insure lower engine acquisition and support costs.

Other examples of competitive aircraft turbine engine multiple sourcing include the F404 engine used on the Navy's F/A-18A/B/C/D. The engine was originally developed and produced by General Electric. Although the engine performed well in the field, the Navy provided Pratt & Whitney an opportunity to develop an engine to compete for the F404 production. Pratt & Whitney developed and successfully tested its version of the F404 engine. A series of "educational" non-competitive buys were awarded to Pratt & Whitney starting in 1985. The first competitive buy between General Electric and Pratt & Whitney occurred in 1988. After the first several lots, the Navy chose not to continue competition. Although the competition was short-lived, the threat of competition resulted in decreased unit prices and program benefits out-weighed program costs.

b. Engine Leasing

The Air Force is currently studying leasing new engines to replace the B-52's TF33 engines. Leasing, instead of buying the engines outright, is a possible attractive option because the Air Force would not have to fund the entire cost up front. Due to the improved fuel efficiency of new engines, the range of the B-52 would be extended by 40 percent. The B-52 H aircraft built in the early 1960s are currently scheduled to remain in the Air Force through the year 2030.

Boeing submitted a proposal to the Air Force, which provides for modification of the B-52H aircraft to accept four engines similar to those used in the Boeing 757 aircraft (RB211-535E4) replacing the current eight TF33 engines. The RB211 engine has 43,100 pounds thrust compared to 17,000 pounds for the current TF33 engine. The RB211-535E4 engine has been in service commercially for 12 years with over 11 million combined hours with inflight shut-down rate of 1 per 60,000 hours and a dispatch reliability rate of 99.8 percent.[3]

Principal benefits from installing the new engines would be:

- Reduced annual fuel costs
- Reduced engine maintenance
- Reduced tanker requirements
- Reduced airlift requirements

These advantages would occur for either buying or leasing the engines. Leasing spreads the cost of the engines over the period of the lease, whereas buying would require the funds up front.

Preliminary results from an IDA investigation of the B-52 re-engining proposal found that neither engine lease nor buy produced saving unless the reduced fuel consumption afforded by the new engines led to a reduction in the supporting tanker force.

C. TURBINE ENGINE INDUSTRIAL BASE

The turbine engine was initially developed in England and Germany in the late 1930s. General Electric adopted the English design during World War II, and in 1942 developed a turbine engine for the Bell XP-59, the first US jet aircraft. These early efforts were followed with the development of jet-powered aircraft such as P-80, F-86 and B-47 in the late 1940s. From this start the United States quickly emerged as the world leader in turbine engines technology and applications. This leadership has been maintained through the combined efforts of the DoD, NASA, and the private sector.

Ten engine manufacturers supply most of the world's requirements for turbine engines as shown in Table III-2. Of these the four major manufacturers listed account for over 90% of the total world market for large engines.

---

[3] Source: Boeing briefing citing Rolls/Allison data.

Engines developed for either the commercial or military markets often have common technology roots. Engines used in military fighter/attack roles, however, require high performance capability featuring high thrust-to-weight ratios plus other unique design requirements as discussed in Chapter II. Commercial engine requirements, by contrast, emphasize high efficiency, reliability, and low cost of ownership which military transport and other utility aircraft can effectively use.

Table III-2. Turbine Engine Manufacturers

Major Manufacturers	Other Manufacturers
Pratt & Whitney	Garrett/Allied Signal
General Electric	BMW (Germany)
Rolls Royce (UK)/Allison	Snecma (France)
CFM (GE/Snecma)	Textron Lycoming
	Teledyne Ryan Aeronautical
	Williams International

Most manufacturers supply engines for both military and commercial markets with the commercial market being dominant.[4] The total engine market has declined during the past few years by 30% due to reduction in the defense budgets following the collapse of the Soviet Union and a downturn in the airline business cycle. However, airline demands of late have shown signs of growth. For the US manufacturers, foreign sales (both military and commercial) have recently become the largest market segment.

D. TECHNOLOGY TRANSITION AND DESIGN VERIFICATION

Technology transition is the process of migrating technology developments to a military or commercial market or between markets. Design verification is concerned with the process of evaluating through analysis, test and operational experience the suitability of materials and components design and the total engine design. Table III-3 summaries the technology transition and design verification process applied to the military and commercial markets.

The major issues associated with technology transition and design verification are reviewed in the following discussion.

4 Office of the Under Secretary of Defense for Acquisition and Technology, *The Report of Defense Science Board Task Force, Jet Engine Commercial Practices Panel Final Report, Appendix D*, May 1994.

Table III-3. Technology Transition and Design Verification Process Comparison

Item	Military	Commercial
Design Emphasis	High thrust-to-weight for F/A aircraft	Fuel economy, reliability, low support cost
Technology Development Programs	IHPTET, other DoD R&D programs, and IR&D	NASA engine projects and engine manufacturers' IR&D, IHPTET
Design Verification	Accelerated mission testing Significant qualification tests	FAA certification procedures
Test Resources	Air Force Arnold Engineering Development Center (AEDC), NASA, and manufacturers' facilities	NASA, AEDC and manufacturers' facilities

1. Technology Transition

Much engine technology is used for both military and commercial engines. Examples of common technology include high temperature coatings, hollow fan blades, turbine blade/vane cooling concepts, brush seals, combustor design and non-metallic composites. Technology transitions have been accomplished for both market sectors in both directions has shown in Table III-4.

Table III-4. Technology Transitions

Commercial to Military	Military to Commercial
Separate engines into modules	High-temperature coatings and air-cooling rotor-blade design
Brush seals[a]	Split cases
Float wall burners[a]	High-temperature materials (e.g., single crystal)
Electronic engine controls[a]	Integrated flight management and fuel control
	Sealing systems

[a] First applied to commercial applications, but technology derived from DoD-sponsored technology programs.

Military technology programs have put emphasis on achieving high performance whereas commercial programs have stressed reducing cost of ownership. Military programs are concerned with low observables, lower weight alloys and structures, higher temperature coatings, turbine alloys and structures, air sealing systems, integrally bladed rotors, ceramic coated bearings, and high temperature composites which are capable of with standing complex mission profiles.

Commercial engine development programs stress fuel economy and cost thus place emphasis on improved aerodynamics, cooling, running clearances, and leakage control. Engine cost is addressed by improving engine manufacturing processes. Engine manufacturers often make use of an Integrated Product Team (IPT) for product definition. The IPT is a multi-functional team with members from design, manufacturing, purchasing, and customer support that works to develop a preferred product definition

that reflects the tradeoffs from each discipline represented. Any deviation from the preferred product design requires management approval. In recent years, the DoD has made increased use of the IPT concept.

It is clear that each market sector has benefited from developments that have occurred in the other market. It is important that this technology and acquisition process transfer continue.

2. Design Verification

Verification entails conducting analysis and/or testing to demonstrate that the item in question can meet operational and environmental requirements. Military and commercial engines share many of the same materials and manufacturing processes. As a consequence, design verification can be similar for military and commercial programs. The Accelerated Mission Testing (AMT) concept has been incorporated into military engine development programs for fighter/attack aircraft. AMT is designed to include rapid throttle changes that simulate a realistic mission profile. Since the ability to withstand a large number of rapid throttle setting changes is not a requirement for airline applications, commercial acquisition practices do not make use of AMT, relying on more limited ground and flight testing and the operational feedback from the rapidly accumulated operating experience.

The DoD and NASA have extensive test facilities that are available for both military and commercial technology verification efforts. For example, the Air Force operates at Arnold Engineering Development Center test facilities that can evaluate engine operation at ranges of speed (0-Mach 3), altitude (sea level to 100,000 ft), and temperature (-100°F to 1200°F). The facility can test engines with thrust up to 100,000 lbs., and a diameter up to 28 ft. These facilities are used to support both military and commercial test programs to meet either military or FAA regulatory requirements.

A major difference between the military and commercial programs is the manner in which they are funded. Military verification efforts often will be defined in a statement of work for which definitive milestones are established. Funding and authorization to proceed to a subsequent phase are often dependent upon proper demonstration, documentation and approval of the prior verification step. In the commercial environment verification efforts follow FAA certification requirements. Because verification activities are company funded, delays for the demonstration, documentation and approvals process may be less, and the development process can be shorter.

E. LIFE-CYCLE PLANNING

1. Planning Cycle

Life-cycle planning is the process used to define the events and the schedule milestones to be followed in the development, production, operation and support of a new engine. For commercial engines, requirements stem from the likely capability of engines to be offered by the competition and the overall market size. Planning begins with an assessment of the respective threats or competition which in turn are translated into engine performance goals. The planning process is driven for the military by the expected threat. Comparing the desired goals to the current engine state-of-the-art provides the means to evaluate the realism or risk of achieving the initial goals. This comparison also permits initial cost estimates to be made. Several iterations of these planning steps may be required to achieve the proper balance among performance, risk, cost and schedule.

Development of a military derivative engine requires about three to four years and five to ten years for new concept application engine. It is of interest to note the disparity between the time required to develop a new concept engine and the time (5-years) needed to develop a new airframe. The engine and airframe development times disparity has been the source of problems on several military aircraft development programs. Commercial development typically takes about one to two years for a derivative engine and four to six years for a new engine for a new airplane type.

Table III-5 provides a comparison between military and commercial engine development planning cycles. The military engine development process is often driven by funding and the specific weapons system phasing, than by the "optimal" technical considerations.

Table III-5. Engine Life-Cycle Planning Comparison

Item	Military	Commercial
Development cycle	3-4 years derivative engine; 5-10 years new engine	1-2 years derivative engine; 4-6 years new engine
Development funding	Military funds	Engine manufacturer funds
Engine requirements	Set by military	Set by engine manufacturer in conjunction with airframe manufacturer for the customer.
Competition	Usually only for early R&D phase; competition for production possible at government option	Competition for production

2. Acquisition Planning

The Life-Cycle Planning process must also consider the acquisition approach to be followed in the development and procurement of the engine. The ability to maintain competition throughout the life cycle is important for achieving low life-cycle cost (LCC).

When military aircraft can use commercial engines, the DoD might benefit by using commercial engine acquisition practices. There have been a number of procurement regulations and laws that have formed contractual obstacles to the economical use of commercial engines in military aircraft. Procurement requirements have included:

- Truth in Negotiations Act
- Marking of Supplies
- Examination of Records (Data Requirements—manuals, TCTOs, etc.)
- Major Systems and Munitions Programs, Survivability and Lethality (Live Fire) Testing
- Selected Acquisition and Unit Cost Reports (CCDRs)
- Subcontracting Plan
- Small and Disadvantaged Business
- Rehabilitation Act of 1973
- Clean Water Act
- Clear Air Act
- Equal Opportunity (EEOC)
- Buy American Act
- Affirmative Action for Disabled and Vietnam Veterans
- Cargo Preference Act
- Trade Agreements Act of 1979
- Walsh Healey Act

The DSB Panel on Jet Engine Commercial Practices in their final report recommended that "The Administration, Congress, and the DoD provide the necessary waivers and exceptions to the various laws, regulations, standards, and specifications that will allow pure commercial practices to be used to procure and support mature military

engine production and support programs...."[5] The panel further recommended that a joint industry government team be established and funded to develop and implement a time phased plan for use of commercial procurement practices where practical.

Military engine development efforts are funded by the DoD. Program Definition and Risk Reduction (Milestone I) and the Engineering and Manufacturing Development Phase (Milestone II) contracts are awarded as the result of competition among the several engine manufacturers. The Production (Milestone III) contract typically is not competed but is awarded sole source to the contractor that was successful during the EMD phase. If the quantity of engines to be procured is sufficiently large, an engine production competition can be brought into the program (e.g., F-15/F-16) thus permitting the DoD to benefit from the competition.

DoD procurements tend to specify and require the demonstration of many detailed engine characteristics adding significantly to the program cost. Moreover, engines used in fighter/attack/supersonic applications have unique requirements thus dictating the design and test efforts to assure proper performance of the delivered engine. (Commercial requirements typically demonstrated are thrust, fuel consumption, weight, operating envelope parameters and the FAA requirements to demonstrate air worthiness.)

Commercial engine developments are internally funded by those companies that chose to participate in a specific market. To be competitive the company must develop an engine that has the required performance with low ownership cost and timely availability. Since companies are free to enter competition and develop any engine of their choosing, multiple engines are usually available for many aircraft applications. With multiple sources available, engine buyers benefit from the production competition. To enter a market, timely product availability is important, while low product cost of ownership is critical in securing and maintaining market share.

Warranty provisions are often included as part of commercial engine procurements. Commercial warranties typically are designed to limit customer risk and encourage implementation of product improvements. Commercial warranty programs tend to be long-term arrangements that often cover parameters such as fuel consumption rates, durability, and cost of ownership. Military warranty programs tend to be shorter term (3-5 years) and address the repair and/or replacement of failed hardware. The return

---

5 Office of the Under Secretary of Defense for Acquisition and Technology, *The Report of Defense Science Board Task Force, Jet Engine Commercial Practices Panel Final Report, Appendix D*, May 1994.

of the failed items to the engine manufacturer does provide failure information feedback and some incentive to improve chronic failure items.

3. Support Alternatives

Commercial engine manufacturers maintain spares resources at parts centers to minimize the customer's inventory needs. Lead times for all but insurance stocks are generally short of the manufacturing lead time. Because there are multiple customers, the engine manufacturers find it economically beneficial to provide on-demand spares support. Because of the unique design of the engines developed under DoD funding, the services typically invest in a large stockpile of engine spares while the engine is in production. This action is taken to avoid the costly reopening of production for spares at some point in the future. The down-side to stockpiling is the high inventory cost and the likely procurement of spares that will not be needed.

Commercial and military maintenance programs are similar since they have nearly the same engine repair tasks. Commercial on-wing maintenance is limited to those activities that will not impact flight schedules. Thus most maintenance is done at the primary Overhaul and Repair (O&R) facility. O&R facilities may be owned and operated by airlines, engine manufacturers, or privately held. Commercial O&R facilities typically do not develop special support structures i.e., elaborate support equipment, technical orders, manuals, training programs. Rather they make use of manufacturer-developed and FAA-approved technical documentation and support equipment.

F. TECHNICAL RISK AND CONTROL

Risk control begins with an assessment of the engine requirements versus the technology state of the art. The technical risks found in an engine development program are related to the difference between the engine requirements and the existing state of the art. It follows that the greater the separation between requirement and the state of the art, the greater the risk. A key part of an engine development effort is to conduct a technical risk identification and control program. Introductions of new materials or processes typically are flagged as potential risk areas requiring that the capability of the new item be fully characterized.

A risk program establishes a course of investigation, monitoring and tracking to assure the resolution of identified risk areas. Control of risk is important for both commercial and military programs but technical risks for high-technology military programs are usually greater than for commercial or military transport. Engines used in

fighter/attack missions are subject to high stresses that are on the performance boundary thus creating a different set of risks than would be present for aircraft used in a more benign manner. Table III-6 summarizes some of the major technical risk differences that exist for military and commercial engine design and development.

Table III-6. Engine Technology Risk Comparison

Item	Military	Commercial
Level of Technical Risk	High for fighter/attack aircraft engines; performance and thrust-to-weight demands push the state of the art; fighter/attack engines have multi-point design requirements	Low to moderate risk dependent on level of competition and cost; single point design
Level of Technical Validation	Fighter/attack engines must demonstrate capability across the full performance envelop to cover all multi-point design requirements	FAA certification requirements and single point design validation less demanding

1. Engine Requirements Setting

Requirements for military engines are driven by the targeted aircraft applications which dictates the performance levels necessary to meet expected threats. Military engine designs for fighter/attack aircraft can be characterized as multi-point requiring a balance be struck to achieve a range of requirements including supersonic capability, weight, thrust, thrust-to-weight, unit cost, performance, stealth, reliability, maintainability, and O&S costs. In the past most emphasis was placed on achieving performance goals with less concern for cost. More recently, in the face of budget restrictions the cost implications of goal choice are receiving greater attention. The concept of cost as an independent variable is being applied to many DoD weapon systems to achieve a more realistic balance between cost and performance. However, it is expected that military engine requirements for fighter/attack aircraft will continue to be performance driven.

Commercial engines are primarily single-point designs (Subsonic cruise) that are designed to meet air worthiness characteristics while achieving required thrust at lowest possible fuel consumption rates. Control and achievement for other design factors generally are market driven. The engine manufacturers must trade off the amount of risk to be taken for a specific area versus the expected competitive pressure. Commercial engine manufacturers often use multi-disciplinary teams to conduct the trades necessary to achieve the proper balance among engine goals.

Requirements are set based on operational needs dictated in the military case by the expected threat and the capability needed to counter the threat. Commercial requirements respond to the economic pressures of the market place and the concern for acquisition and low support costs. The requirements for either the military or commercial environments dictate different design choices to provide the operational capability required. Risk enters depending on the technology maturity that underlies the design choices required for either operating environment.

2. Risk Control

Engineering and design processes common to both commercial and military engine programs are used to address many of the performance risk issues. Military programs have formal risk control programs such as Engine Structural Integrity Programs (ENSIP), ENSIP requires the development of formal risk assessment plans and periodic submission of reports documenting the progress made in risk reduction based on field data. Military programs in addition to performance risks quite often include requirements for control of reliability and maintainability risks.

Commercial engine risk reduction efforts are directed internally by the cognizant manufacturer's engineering and manufacturing teams. Warranty and guarantee programs by use of overall cost per flight hour requirements provide redress to the customer for support cost risks

3. Risk Amelioration

Risk control and reduction requires that design analysis and/or test be accomplished to evaluate the areas of concern. Military aircraft (particularly supersonic aircraft) undergo more ground and flight testing than commercial engines. Testing is directed at operability, performance and endurance cycling to identify problems that may constitute risk areas. Prior to entering operational service the engine must demonstrate that it meets all air worthiness requirements. Safety, reliability, durability and producability issues drive similar tasks for both commercial and military programs.

Military tests and initial operating experience provide a basis to identify engine performance or reliability problems. Problem resolution is accomplished by the issuance of time compliance technical orders (TCTOs). Post-certification sustaining engineering for both military and commercial applications are similar. Military improvements are often tied to formal CIP efforts. Future CIP programs could be scaled back if proper

incentive programs tied to early maturation were established with the engine manufacturer.

Commercial engines accumulate hours rapidly after introduction into service providing an in-depth operating experience data base to identify problems. As safety or reliability problems are found, commercial service bulletins are developed and issued to correct the problems. Support by the engine manufacturer for addressing non-safety or reliability issues are driven largely by the potential for increased sales.

4. Summary

Commercial acquisition is not now appropriate for the development of engines for application to military high performance supersonic aircraft due to range of unique high requirements and their attendant high risk. Due to the possible high risk the requirements setting cannot be left to the engine manufacturer as in the commercial case. Rather it requires that they be set by the interaction of the military user, the airframe builder, and the engine developer. Due to the risk it is important that a series of rigorous assessments be made to determine if the evolving design and materials are capable of performing as intended within cost constraints. Given the requirements goals it is expected that the risk assessment documentation and oversight process could be simplified emulating the commercial approach. For example, the IPT process used for commercial engine definition could be used for setting military design requirements.

G. FINANCIAL AND MANAGEMENT RISKS

Financial and management risks are an inherent part of the development of a new or derivative turbine engine. Risks often stem from technology problems as just discussed, leading to cost over-runs and schedule slippage. Financial risks can also result from price competition pressures, inflation or unforeseen problems. It is management's task to anticipate and minimize financial risks to the extent possible. Military and commercial engine development and production are both subject to financial risks. Table III-7 compares some of the levels of risk attendant to military and commercial engine acquisitions.

Table III-7. Financial and Management Risk Comparison

Item	Military	Commercial
Level of Financial Risk for Engine Manufacture	Very low. Profit margin may be restricted, but low likelihood of bankruptcy	Very high. A major error could bankrupt. Profit potential much greater.
Level of Administrative and Contractual Constraints	Very high due to security, Mil-Stds, and government procurement regulations	Low, minimal management interference
Level of Public Exposure and Disclosure	High if difficulties are encountered. Adds cost and affects schedule.	Limited near-term but may lose future sales

1. Military Developments

Military engine developments typically are funded by the DoD, but carry the risk of cost overruns that can affect both the military customer and the engine manufacturer. The company may invest its IR&D funds to develop engine technology that may help the company to compete for the initial competitive development contracts. New engines developed for fighter/attack aircraft applications often push the state-of-the-art to gain performance advantage over potential adversaries. These state-of-the-art goals of a new engine carry greater technical risk and in turn higher financial risk.

Military engine development programs also are concerned with meeting schedule goals. As noted in the prior discussion of Life Cycle Planning, there is a mismatch between the 5-10 years required to develop a new engine and the 5-7 years required for a new airframe. There have been programs that attempted to accelerate engine developments to coincide with the airframe schedule. This often leads to premature fielding of engines that have not been fully tested and were later found to have serious operational problems.

Two available strategies are either to 1) use derivative engines which have shorter lead times or to 2) sponsor the development of state-of-the-engine enhancements as general technology programs not targeted for a specific aircraft. The current IHPTET[6] program is a military program designed to mature and improve the process for developing and demonstrating advanced engine concepts to lower the risk of transitioning new development or derivative engine technology. From a broad perspective, IHPTET's overall goal has been to maximize the technology output for the combined government/industry investment in engine technology development. A prior engine

6 Integrated High Performance Turbine Engine Technology (IHPTET) Program. See Development/ Production Process Investment discussion in this report.

technology program called the Advanced Turbine Engine Gas Generator Program (ATEGG), begun in mid-1960s, supported engine performance and durability enhancements.

Budget limitations may require that trade-offs be conducted among engine design features. Military investment decisions for engines typically are based on the following criteria listed in order of importance:

- Safety of flight
- Mission performance
- Mission readiness
- LCC

Continuing budget restrictions and the more prudent application of commercial practices has brought Design-to-Unit-Cost as an independent variable along with other reduced LCC initiatives higher in the priority decision scale.

2. Commercial Developments

In the past, commercial engines were financed internally by the individual manufacturers. For new high-performance engines whose development cost can exceed $1 billion, it is generally no longer feasible for one manufacturer to assume the total risk. International partnerships have been formed to share the financial and market risk. Use of international partners increases the likelihood that the engine will be selected by non-US airlines. Examples of international joint engine developments include the CFM56 and the V2500 engines.

Development of a new engine carries the potential of financial risk to both the developer and the buyer. Commercial engine manufacturers have the risk of not recovering their investment for developing the engine and not providing the desired profit margin for the units produced. This can be caused by costs exceeding target goals and/or insufficient sales. Exceeding cost goals can stem from improper management control and/or unexpected technical problems (risks). Insufficient sales can result from general market conditions, failure to develop a technically superior product or lack of competitive pricing.

The ability to develop and produce an engine on schedule is another concern of management. In the commercial market the availability of the engine to coincide with aircraft production is critical to the airframe manufacturer and the ultimate customer, the

airlines. Failure to meet engine delivery schedules can tie up aircraft worth millions of dollars and lead to insufficient load carrying capacity impacting growth and market share for the engine maker and the customer.

Risk reduction actions are established by the engine manufacturer to enhance the acceptability of the final product. Manufacturer component improvement investment strategy decisions are rooted in the expected return-on-investment and are guided by:

- Does the change reduce maintenance cost?
- Does it reduce warranty exposure?
- Does it lower the risk of meeting life guarantees and fuel cost?

Success requires management to carefully balance engine performance, quality and price for the markets targeted.

The military has made use of commercial engines in several cases (C-17, KC-10, KC-135R, etc.) The engine manufacturer for the C-17 noted that his cost grew over the commercial base line due to:

- Military-unique requirements (weight and performance improvements required to meet military system specifications)
- Data (documentation requirements not provided to commercial customers)
- Engine Structural Integrity Program (ENSIP)
- Technical manuals (normal commercial manuals not used)
- DPRO oversight
- Warranty requirement (over and above normal commercial agreements)

Each of these items impacted cost and time thus not allowing the government to fully benefit from the cost advantages of the commercial market. Although the intent of the procurement was to use commercial practices, issues that arose regarding access to financial information and data rights initially presented obstacles to program.

H. DEVELOPMENT/PRODUCTION PROCESS INVESTMENTS

Prudent investment in the resources and processes needed to design and produce engines can pay dividends to the engine manufacturer. Targets for process improvement can cover a broad range from base materials, design improvements to support ease of manufacturing, test resources, fabrication automation, and quality measurement techniques.

Since most manufacturers develop and sell engines to both the commercial and the military markets, an issue of concern is the development and production process relationship between the two activities. Under the discussion of technology transition and verification we saw that there has been a significant flow of technology from the commercial to the military and vice-versa. It is thus logical to expect that underlying development and manufacturing process technology would flow between the two product sectors. Other concerns are the source of funding to underwrite their cost and the division of cost between the two market areas.

In 1988 the DoD initiated the Integrated High Performance Turbine Engine Technology (IHPTET) program, significantly expanding prior turbine engine technology goals. The program is being accomplished jointly by the Air Force, Army, Navy, NASA, and all major US turbine engine manufacturers. The goal of this program is by the year 2003 to increase engine thrust-to-weight capability by 100% and increase combustor inlet temperature by 400 degrees F over the 1988 levels.[7] These capabilities are intended to be transitioned first to the F414 engine for the F/A-18E/F, the F119 engine for the F-22 and ultimately to civil aircraft engines.

The military Value ECP process permits the company to share the savings that accrue from design or process changes that reduce cost of the military programs. Incorporation of military Value ECP may be considered for commercial engines if there is sufficient economic pay off (reference prior discussion on financial risk).

Commercial engine development and production process investments for the most part are company funded. The company retains design and data rights cost for internally funded developments. Military engine developments are almost always funded by the government and for their investment, the military expects ownership of the resulting intellectual property.

Dual-use manufacturing processes are employed for the commercial and military versions of the same series engine. Investments and developments in these dual use processes obviously would support both commercial and military engines. To maintain commonality, changes in processes and parts developed for commercial engines are often incorporated by engine manufacturers into military products at no added cost.

7 The goals cited are restricted to this class of aircraft, and it should be noted that there are other goals for other aircraft classes as well as goals for acquisition and maintenance cost reduction.

Government-directed changes for military engines are funded by the military and are not normally incorporated into commercial engines.

I. SYSTEM INTEGRATION

System integration is the process of bringing together the airframe, engine, and avionics to permit separate subsystems to function in a cohesive manner to achieve the best performance for the total aircraft. This requires that compatible interfaces be created among the subsystems that accommodate the following integration elements:

- Mechanical structure
- Aerodynamics
- Air flow
- Electrical
- System functions
- Emissions (ozone, smoke, and noise)
- Observables (RF and IR)
- Stress, weight, and balance

Commercial airframers are usually responsible for the integration of the propulsion system including engine, nacelles and pylons. The nacelles and pylons may be supplied by the airframer or by a subcontractor. For subsonic aircraft, the military may supply the engines GFE (bought by the government and furnished separately) while the nacelles and pylons are supplied CFE (either supplied by the airframer or a subcontractor). Supersonic aircraft typically do not use pylons and require application unique design of the inlet and exhaust components.

J. TEST VERIFICATION

Verification of the engine design is accomplished by subjecting production configurations to a qualification test. Commercial and military basic testing approaches are largely the same for subsonic aircraft with the following key parameters being evaluated:

- Thrust
- Thrust Specific Fuel Consumption (TSFC)
- Rotor Speeds
- Temperatures

- Pressures
- Vibration and Noise Levels

Military engines are required to meet specifications requirements contained in the development contract. These requirements generally are more exacting than those designated for commercial engines. As a consequence, the test programs are more extensive and costly. Military testing of supersonic aircraft features cycling the engine operating point to simulate the profiles encountered during fighter and attack missions. As noted in the prior discussion on technology verification, the Accelerated Mission Testing (AMT) concept has been incorporated into military engine development and qualification programs for fighter/attack aircraft.

Commercial test requirements are based on FAA specifications and the manufacturers' internal standards. Commercial quality standards are in the process of changing to the International Standards Organization (ISO) 9000 series. Air Force and Navy are also considering using the ISO 9000 series in lieu of the current engine Mil STDs.

In summary, military test verification programs are generally more robust than their commercial counterparts. Adoption of the commercial verification test procedures would require improvement in the scope and depth of the of the tests now conducted for commercial evaluations. Alternatively, some relaxation of the current military verification test oversight, data and documentation requirements could lead to streamlining the military procedures.

K. CUSTOMER AND VENDOR INTERFACES

1. Military Interfaces

Military contracts both development and production typically contain many program requirements and milestones that must be documented with deliverable data packages that are subject to review and approval. Examples of these requirements are:

- Cost and pricing
- Small business plans and reports
- EEO plans and reports
- Configuration control plans and reports
- Small business plan

- Acquisition plan
- ECPs
- Contract changes
- Cost certification
- Reliability, maintainability, and logistics plans and reports
- Test plans and reports
- Make or buy reports

Aside from configuration control very few of these documents are required for commercial engine development or production. The reduction in administrative burden by the use of commercial practices for the military customer would be very significant.

When the engines become operational the engine manufacturer will provide warranty support if this was required by the production contract. Depending on the terms and conditions of the warranty some product improvement can be provided from the feedback that results from the return of the failed items. Major product improvement results from government-funded component improvement programs (CIP). These efforts can range in scope from a few million to major efforts extending for several years costing hundreds of millions. The military normally does not make use of the support facilities (spares and maintenance facilities) that the engine manufacturer provides to the commercial market

2. Commercial Interfaces

The engine development process begins with the engine manufacturer contacting airframe companies and the airlines to identify the opportunity for new or derivative engines. Should a potential market be sensed the engine manufacturer gathers information regarding general engine requirements in terms of the unit cost, thrust, fuel consumption, noise characteristics, pollution emissions, support cost goals, quantities needed and availability schedule. Development of the engine begins when the engine manufacturer makes a firm sale and/or is convinced that sufficient market exists to warrant his engine development investment.

Since commercial engine developments are funded by the manufacturer there typically is limited contact with the customer (airline) other than dialog to firm up early estimates and to assure that projected market conditions still hold. The engine developer will interface with the airframe manufacturer to acquire information necessary to establish the interface between the targeted aircraft and the engine. The engine

manufacturer directs the design, provides configuration control, and conducts those tests deemed necessary to assure meeting targeted objectives. During development the engine manufacturer will contact and interfaces with several hundred material and component vendors and suppliers.

During the development process, design analysis and test results are reviewed by designated engine manufacturer employees who have been authorized by the FAA to function in that role. The FAA periodically will conduct oversight inspections to ensure that the specified procedures are being correctly followed. Configuration control for the engine is maintained by the manufacturer, and changes are easier than under the military change control board process. As the development nears completion, the manufacture conducts, documents and demonstrates the air worthiness characteristics as required by FAA regulations

After the engine enters service, the interface between the engine manufacturer and the customers increases and will be maintained through the engine's life. These interfaces include:

- Spares support
- Maintenance support (support equipment, technical manuals, repair facilities)
- Warranty administration
- Sustaining engineering in the form of service bulletins directing inspections, changes in maintenance or operating procedures changes and/or modifications

The airlines expect and demand excellent product support for engines. Past support experience with a manufacturer can influence the individual airline in its future engine buys. Engine manufacturers are aware of this and strive to maintain a high degree of product support.

3. Summary

The interfaces in the commercial and military cases are basically the same but differ in the timing and the complexity of the interface dialog. Military interfaces with the engine manufacturer are extensive since they direct both development and production. After delivery the interfaces diminish unless a CIP effort is initiated. For the commercial case contact between the engine manufacturer and the customer is somewhat limited during development and production. With delivery of the engine operational support is provided throughout the engine's life.

L. ACQUISITION PROCESS SUMMARY

Reviewing the total spectrum of issues associated with military and commercial engines leads to the conclusion there are similarities and differences between the commercial and military acquisition processes. Some of the principal differences and similarities are presented below.

- Similarities:
  - Share the same industrial base
  - Common production facilities
  - Similar development, manufacture, and support processes
  - Share many technology developments
  - Several engines types are used by both military and commercial customers
  - Verification tests cover many of the same parameters
  - Designs stress, low ozone, smoke, and noise emissions
  - Share parts and materials vendors
  - Configuration control is required
  - Share some design procedures and engineering standards
- Differences:
  - Fighter/attack engines are multi-point designs, commercial engines are single-point designs
  - Military funds engine development and retains data rights
  - Military directs and controls engine development and production and requires the delivery of extensive data for review and approval
  - Military audits the engine manufacturer's cost and negotiates profit margins
  - Military normally competes design demonstration/validation and awards engine development and production sole source, although production competition has occurred (F-16C/D)
  - Military has funded extensive CIP efforts to improve engine durability as shown to be needed by operational experience
  - Military procurement regulations have posed obstacles to the purchase of commercial engines in the open market, but through persistence, these obstacles have been surmounted

- Commercial engine manufacturers establish the characteristics for engines they intend to develop in cooperation with commercial airplane manufacturers and customers
- Engine manufacturers fund development of commercial engines and retain data rights
- Commercial engines take 4-6 years to develop while military engines take 5-10 years, nominally
- Engine manufacturers direct and control commercial engine development, production and what could be characterized as CIP
- Commercial manufacturers set price (and profits) by negotiation in open competitive market
- Commercial aircraft customers compete engine applications
- Commercial customers often rely on engine manufacturers or third parties for operational and maintenance support
- Requirements for military engines for supersonic fighter/attack applications are more demanding than for commercial engines and tend to push the state-of-the-art, creating higher risk programs.
- Fighter/attack aircraft engines have requirements for low radio frequency/infrared observables

The differences far outnumber the similarities. Due to significant economies offered, it is important to consider greater use of the commercial acquisition methods. Considerable common technology production processes, and industrial base make it practical to use commercial practices in some military engine acquisitions.

General Electric in their report to the DSB Panel on Jet Engine Acquisition stated that "Throughout their history of design, development, production and field support GE Aircraft Engines (GEAE) jet engines have been designed, developed, and produced in the same facilities, using the same materials and processes, the same people, the same sub contractors/suppliers and a single GEAE system of policies and procedures. Where unique military or commercial requirements had to be met they were incorporated into the single system and tailored appropriately to satisfy those requirements."[8] They further stated that "their system can satisfy all customers with an essentially commercial practice

---

8 General Electric Aircraft Engines, *DoD Acquisition of Jet Engines Using Commercial Practices,* October 1993.

acquisition for in-production engines." They argue that this approach has been proven by the successful application of commercial engines in military subsonic applications.

To make greater use of commercial engine acquisition practices the next logical step would be to apply them to the acquisition of mature in-production military supersonic engines. However, use of commercial acquisition practices in the design and development of military supersonic engines would represent a significant departure from the current norm with a number of attendant risks as discussed above.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Examination of turbojet/turbofan engine performance characteristics for the range of aircraft used by the DoD, and the commercial and military acquisition practices and processes used for engine development and production, has led to the following general conclusions:

- The commercial aircraft turbine engine acquisition process has been proven to produce high-quality, efficiently operating engines for subsonic cruise flight applications capable of achieving desired operating characteristics at costs less than their military equivalents.
- Commercial engine processes in the United States are not now intended to provide engines to meet supersonic flight requirements.
- Engines developed for commercial use have the thrust and operating characteristics that meet many of the military subsonic aircraft engine requirements related to transport, unmanned air vehicles, utility aircraft, and selected bomber applications. This has been proven by the actual use of commercial engines for military applications such as the C-17 and the KC-135R.
- The decision to re-engine a military subsonic aircraft requires that the aircraft performance be shown to improve significantly and that the projected operating and support cost savings exceed the cost of acquiring, integrating, testing and installing new engines (e.g., KC-135R).
- The feasibility of using commercial engine acquisition practices for the acquisition of high-performance, supersonic military aircraft engines has not been tried and is not considered likely.

B. RECOMMENDATIONS

The following general recommendations were developed based on the conclusions reached:

- The DoD should continue to make use of current commercial subsonic engine products for both engine retrofit (KC-135R) and new production (C-17).

- The DoD should use the commercial engine development process and FAA oversight procedures to the extent practicable for, subsonic transports, tankers, unmanned air vehicles, utility aircraft, and selected bomber applications.
- Fighter/attack aircraft engine development should make use of selected commercial practices, including use of integrated product teams, design to unit cost, and simulation and modeling.
- Military engine support may be streamlined by using commercial practices related to data, technical documents, and support equipment.
- Spares inventory for commercial engines in military applications may be reduced by making use of engine manufacturers spares facilities and resources. Provision must be made to accommodate wartime requirement surges.
- The DoD should review procurement processes to reduce complexity and remove obstacles to the military use of commercial products.
- The DoD should continue to sponsor turbine engine technology development for subsonic and supersonic flight to maintain the US leadership role.
- The DoD should continue to sponsor CIP for military engines to ensure safety of flight and operability, supportability, and durability.

Table IV-1 presents a series of more detailed steps that should be taken for a number of issues for the military to make greater use of commercial turbine engine acquisition practices and processes.

Table IV-1. Conclusions and Recommendations for Military Use of Commercial Turbine Engine Acquisition Practices and Processes

Issue	Conclusion	Recommendation
Contract Terms and Conditions	Military contract requirements interfere with normal commercial acquisition methods	Move toward commercial practice and base contract terms and conditions on FARs and DFARS mandated by law excluding those for socio-economic and special interest requirements
Data and Data Rights	Data delivery requirements specified in many contracts considered excessive	Limit the amount of data delivered to the government; data rights should be Limited Rights for government use only
Government Production Surveillance	DoD production surveillance continues through the engine production	Delete or reduce activity on mature production lines
Quality Assurance Program	DoD quality requirements duplicative of those used by the engine manufacturers on commercial lines	Make use of the existing commercial quality assurance system that is in compliance with Federal Aviation Regulation Part 21; audits would be limited to FAA QASAR or ACSEP System reviews. Day-to-day data analysis and audit would be accomplished by Designated Manufacturing Inspection Representatives (DMIRs), company employees certified to act on behalf of the FAA
Configuration Management	DoD configuration management system is duplicative of commercial practice	Adopt FAA approach using Designated Engineering Representatives (FAA-DERs) to review and approve design changes after Type Certification is issued
Engineering Technical Data	Data requirements considered excessive	Engineering drawings and related documents should be developed following normal commercial practices
Technical Publications	DoD standards for technical publications are considered excessive	Use standard commercial manuals as appropriate
Spares Inventory	Acquiring engine spares can be duplicative of commercially available spares that can be acquired as needed	Use commercial supply resources or warranty
Support Equipment	Commercial support equipment can meet many of the engine test requirements	Use commercial support equipment as appropriate

APPENDIX

CHARACTERISTICS OF MAJOR MILITARY AIRCRAFT ENGINES

Table A-1. Major Military Subsonic Aircraft and Engines

Aircraft	Engine	Thrust (lbs.)	Engines/ Aircraft	Total Aircraft[a] (approx.)	Commercial Engine Counterpart
A-10	TF34-GE-100	9,065	2	370	—
AV-8B	Pegasus 11-61 (F402)	23,800	1	200	—
B-2	F118-GE-100	19,000	4	21[b]	—
B-52H	TF33-P43W	13,750	8	90	JT3D
C-141	TF33-P7	21,000	4	240	JT3D
C-17	F117-PW-100	40,000	4	120[b]	PW2040
C-5A/B	TF39-GE-1/1C	40,000	4	130	CF6
E-3B/C	TF33-PW-100	21,000	4	30	JT3D
EA-6B	J52-P-408	11,200	2	130	—
F-117A	F404-GE-F1D2	11,000	2	55	—
KC-10	F103	52,500	3	60	CF6
KC-135 (R)	F108-CF-100	24,000	4	550	CFM56B
S-3B	TF34-GE-2/400B	9,275	2	120	—

Source: *Jane's World Air Force*, Sep 96.
[a] Approximate quantity at the end of FY96 for that model.
[b] Current estimate of planned buy.

Table A-2. Major Military Supersonic Aircraft and Engines

Aircraft	Engine	Speed (Mach)	Thrust (lbs.)	Engines per Aircraft	Total Aircraft[a] (approx.)
B-1B	F101-GE-100	1.25	30,000	4	100
F-14A/B/D	F110-GE-400	> 1.8	27,300	2	300+
F-15A/B/C/D/E	F100-PW-100/229	2.5	23,830	2	750+
F-16A/B/C/D	F100-PW-200/220	2.0	23,830	1	—[b]
F-16C/D	F110-GE-100/129	> 2.0	27,000	1	1,500[b]
F-22	F119-PW-100	1.7	35,000	2	339[c]
F/A-18A/B/C/D	F404-GE-400	2.5	17,700	2	800
F/A-18E/F	F414-GE-400	1.8	22,000	2	548[c]

Source: *Jane's World Air Force*, Sep 96.
[a] Approximate quantity at the end of FY96 for that model.
[b] The total for both F-16 engines is 1,500.
[c] Current estimate of planned buy.

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
November 1997

3. REPORT TYPE AND DATES COVERED
Final Report, Jul 1996–Nov 1997

4. TITLE AND SUBTITLE
"Potential for Broader DoD Use of Commercial Turbine Engine Acquisition Practices and Processes"

5. FUNDING NUMBERS
DASW01 94 C 0054
T-F7-1010

6. AUTHOR(S)
J. Richard Nelson and Bernard L. Retterer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22311-1772

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Document D-1990

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Mr. Dean Gissendanner
USD(A&T)/AW
Room 3E1081, The Pentagon
Washington, DC 20301-3090

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12A. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12B. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Seeking ways to reduce military aircraft expenditures, IDA investigated the potential for expanded military use of commercial acquisition practices and processes to acquire and maintain aircraft turbine engines. This commercial acquisition process includes the Federal Aviation Administration (FAA) certification procedure for aircraft turbine engines. IDA reviewed the extent to which commercial engines can meet military aircraft application requirements. The review compared commercial aircraft turbine engine acquisition practices and processes to those used by the military. Past use of commercial subsonic turbine engines in military transport and similar utility aircraft has clearly shown that commercial practices and processes can be used successfully to develop and produce engines for subsonic military applications. However, the examination of the technical requirements for subsonic and supersonic aircraft engines found several design differences. IDA recommends that (1) DoD retain the present military turbine engine development process for supersonic military fighter/attack aircraft, and (2) DoD engine procurement procedures be streamlined by incorporation of the proven compatible commercial aircraft engine acquisition processes for subsonic transport, tankers, unmanned air vehicles, utility aircraft, and selected bomber applications.

14. SUBJECT TERMS
Aircraft Engines; Turbojet Engines, Turboprop Engines; Acquisition; Commercial Aircraft; Military Aircraft

15. NUMBER OF PAGES
63

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

UNCLASSIFIED